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Lawrence Livermore
National Laboratory
University of California

In Situ MICROBIAL FILTERS
Chico Municipal Airport Site

Resting-State Biofilter Concept Proven in Field Test

An interdisciplinary team from Lawrence Livermore National Laboratory has successfully demonstrated the resting-state (no nutrients) *in situ* microbial filters approach for remediating groundwater contaminated with trichloroethene (TCE). A nominal 400-ppb TCE stream was bioremediated to less than 10 ppb; bioremediation continued for 40 days after the bacteria were injected. This accomplishment has eluded researchers for over a decade and has the potential to revolutionize groundwater remediation. This field test was jointly sponsored by the Department of Energy's Office of Technology Development, Brown and Caldwell, and Victor Muscat Trust, and conducted under the approval of the California DTSC.

Chico Municipal Airport Site Characteristics

The Chico Municipal Airport site contains a single groundwater contaminant plume that is 2 km long in the NE-SW direction and about 400 m wide (Figure 1). TCE is the sole groundwater contaminant; concentrations are less than 2 ppm. Contamination is restricted to a confined aquifer about 15 m in vertical extent (Figure 2). The aquifer is in highly heterogeneous volcaniclastic sediments where grain size ranges from cobbles to clay. Permeability and porosity have been estimated from pump tests to be about 3 D and 40% in the test area. Site groundwater is very dilute, with the total dissolved salt concentration at about 220 ppm; the pH has a range of 7.5 ± 0.2; dissolved oxygen has been measured at 5 ± 2 ppm.

Tracer Test

A bromide tracer test was conducted two weeks before the biofilter field test and at the same location. A huff-and-puff scheme was utilized. A 100-ppm bromide solution was injected in well #13 (Figure 1) for about 7.5 hr at 4 L/min, followed by a 2.5-hr injection of a chaser with no bromide; after injection, groundwater extraction was immediately initiated at the same rate.

Analysis of the groundwater samples taken from #13, NW, and SE conclusively demonstrates a high degree of media heterogeneity at the scale of the tracer test (Figure 3). The data show an azimuthal heterogeneity in porosity and permeability and suggest that the injected solution did not have access to 25% to 30% of the aquifer. This implies that any biofilter will have dramatic spatial variations in it attached cell population density.

Field Test Design

Field testing of the biofilter consisted of a huff-and-puff study similar to that described for the tracer test. Well #13 was used for both injection and withdrawal; it has a history of TCE concentrations in the 400 ± 100 ppb range. Approximately 6.5 kg (dry weight) of a nonpathogenic methanotrophic bacteria (*Methylosinus trichosporium* OB3b) were suspended in an aqueous solution and injected into the aquifer — without any nutrients — at a rate of 4 L/min for a period of 10 hr. The bacteria had previously been cultured at a unique LLNL bioreactor facility. A portion of the injected cells attached to the subsurface soil as they flowed through the pore spaces, forming a fixed-bed bioreactor. Modeling indicates that the biofilter zone is roughly spherical with a radius of about 1 m (Figure 4).

At the termination of injection, groundwater extraction was immediately initiated at the same well (#13) at 4 L/min for 30 hr, after which it was reduced to a rate of 2 L/min. The concept of the huff-and-puff test is that extraction brings contaminated groundwater into the biofilter region where it is remediated as it flows toward the central well. Extraction and monitoring will occur at this rate until the biofilter's TCE-degrading capacity is exceeded. We estimate this will occur after about one month.

Field Test Results

Analysis of samples taken at the central well (#13) shows a dramatic decrease in TCE concentration: from about 400 ppb to less than 10 ppb during the initial stage of our extraction (Figure 5). These results are compelling proof that an *in situ* biofilter was established and that virtually complete biodegradation of TCE occurred for the first 60h of the test. This performance is especially striking because only about 70% of the aquifer was contacted, as shown by the tracer test. Biofilter performance gradually decreased for the remaining 37 days of the test until background TCE concentrations were recovered in the main well.

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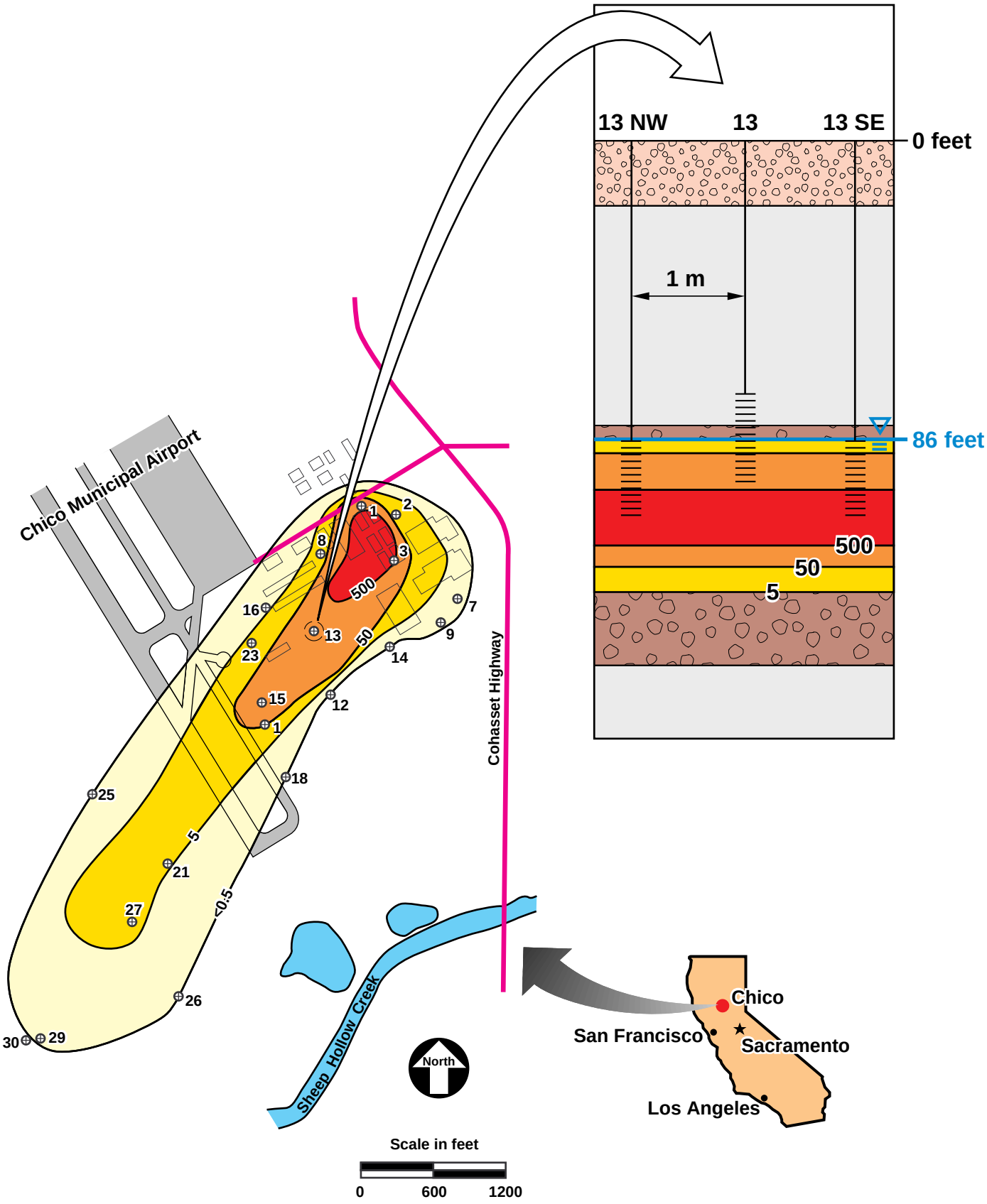

Figure 1. Location and geometry of the TCE plume at the Chico Municipal Airport. The plume is about 2 km long and 400 m wide; the 500-, 50-, and 5-ppb TCE contours are shown. The inset displays a cross-section of the central injection and extraction well (#13) and the two adjacent monitoring wells (NW and SE). Data from Brown and Caldwell.

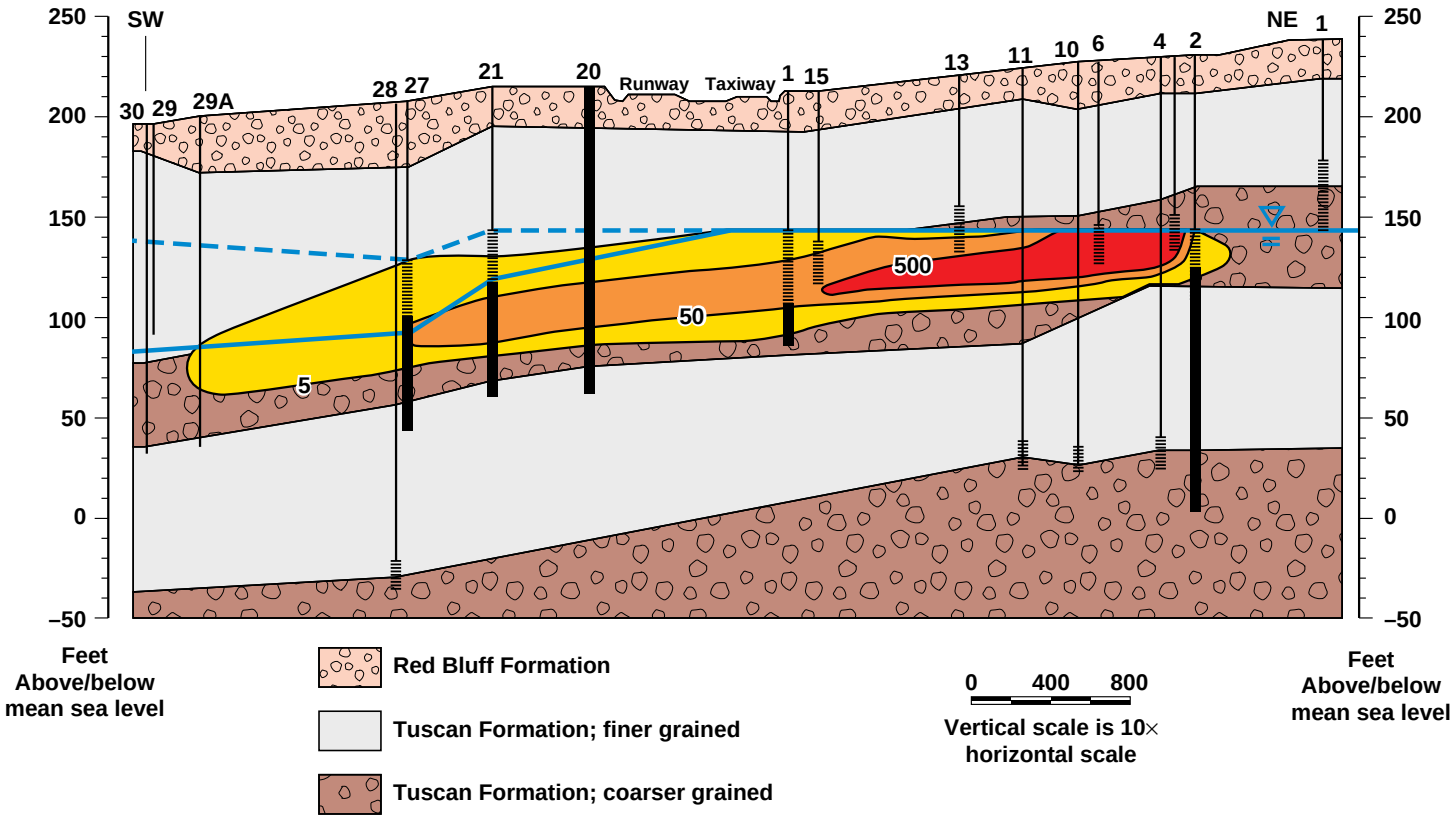

Figure 2. Geologic cross-section down the long axis of the TCE plume, showing well projections (including screened intervals), stratigraphy, water-table, and TCE contours (in ppb). Data from Brown and Caldwell. The contamination is restricted to a confined unit of the Tuscan Formation, which has a top surface that ranges from about 15 m to 30 m in depth and which has a total thickness of about 15 m.

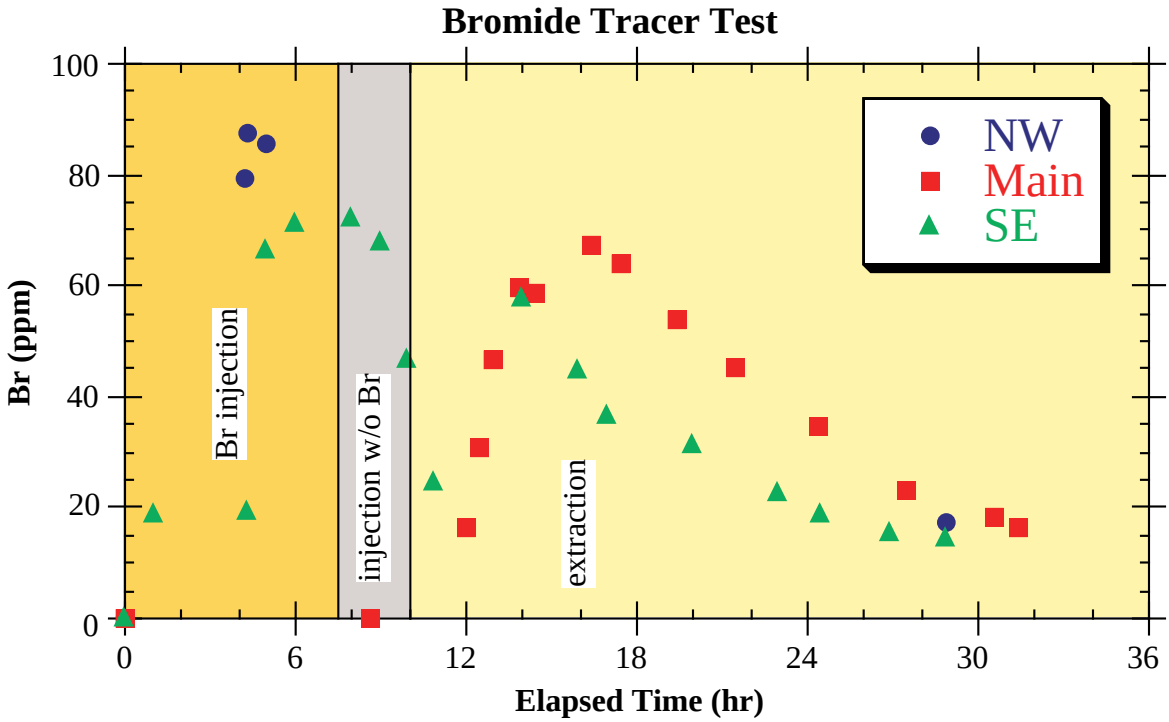

Figure 3. Results of bromide tracer test conducted at the same location as the biofilter field test. Data collected at the main injection and extraction well (#13) and the two monitoring wells (NW and SE) conclusively show that the aquifer has a high degree of heterogeneity. This will result in spatial variations in the attached cell population density in an emplaced biofilter. The data also show that the injected bromide fluid contacted only about 70% of the aquifer, since a maximum concentration of 70 ppm was measured out of the injected 100 ppm.

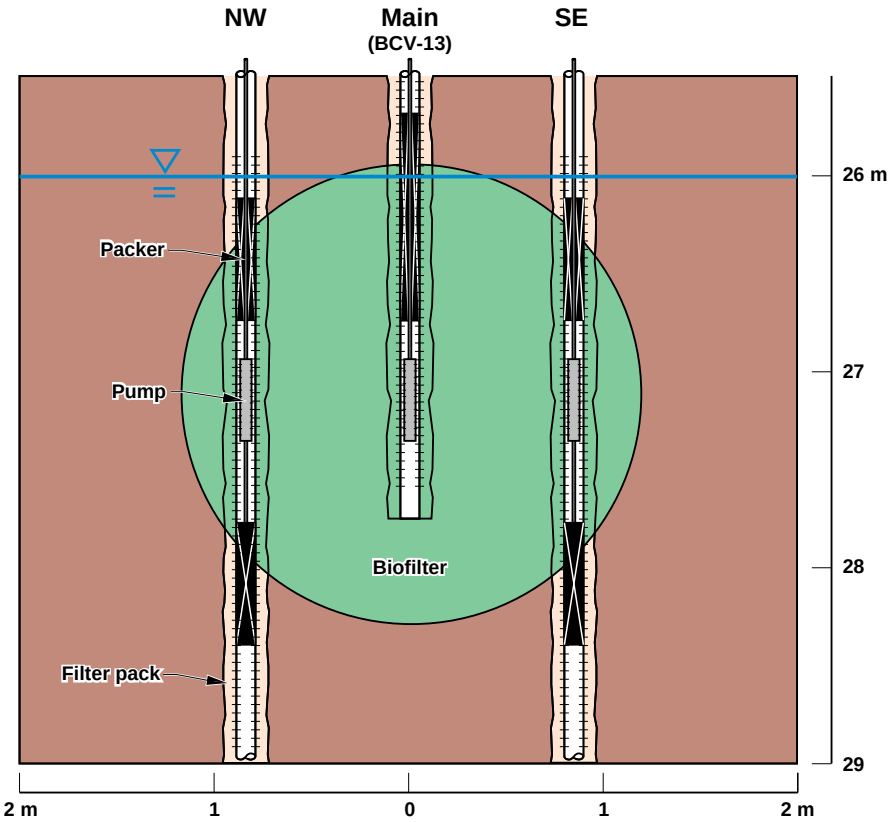

Figure 4. Highly idealized cross-section of emplaced biofilter. Bacteria were injected at the main well (#13) at a concentration of 3 Gcells/mL and at a rate of 4 L/min for about 10 hrs. This established an attached spherical biofilter about 1 m in radius, though media heterogeneities result in significant departure from a spherical shape. Wells NW and SE, located about 80 cm away, enabled monitoring of the injection process. Immediately after injection, groundwater was extracted from the main well at a rate of 4 L/min for the subsequent 30 hr and then at 2 L/min. Groundwater samples were taken at all three wells to monitor TCE concentrations.

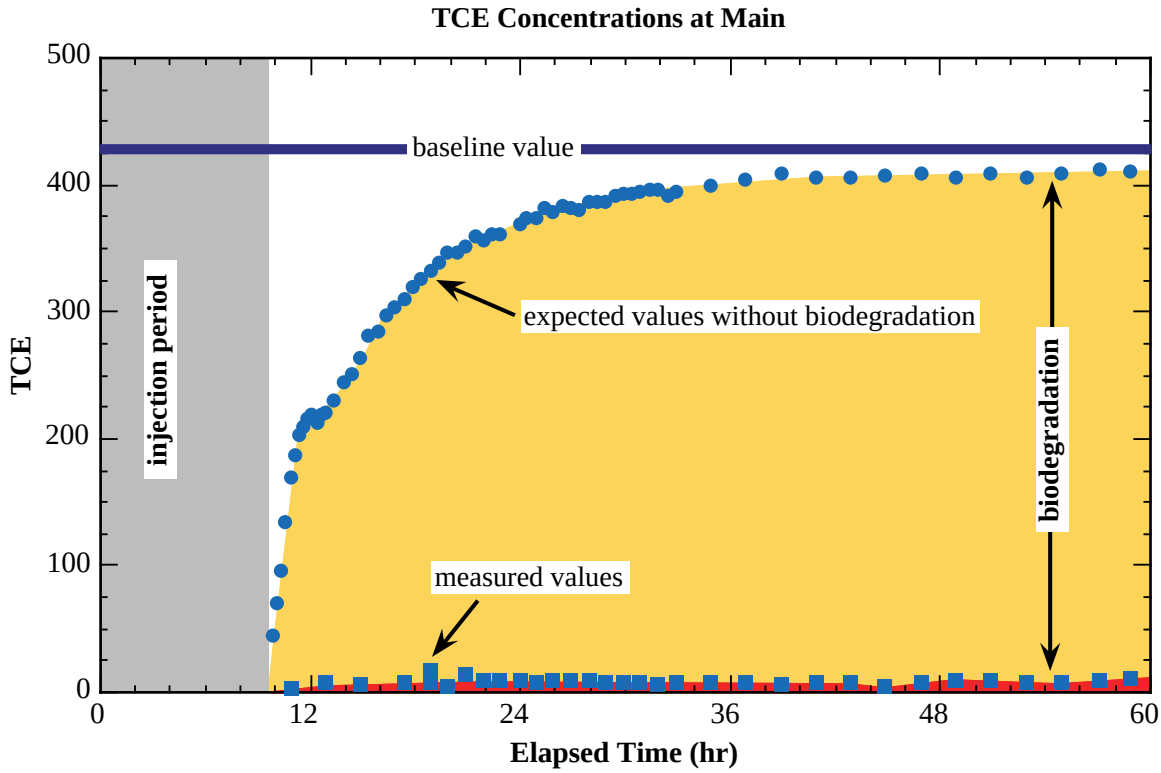

Figure 5. TCE concentrations in groundwater extracted from Main (#13) as a function of time. Baseline values are from samples collected prior to cell injection. There are no data available for 0 to 10 hours because a cell-laden aqueous solution (3 Gcells/mL) was being injected at a rate of 4 L/min into the aquifer through Main. A quasi-spherical attached biofilter about 1 m in radius was formed. After injection ceased, groundwater was extracted from Main at a rate of 4 L/min for the first 30 hr and then at a rate of 2 L/min. Results conclusively show virtually complete biodegradation of the ppb TCE stream, from 425 ppb to less than 10 ppb.